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THE DIAMOND AS A NEW ELECTRONIC MATERIAL

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16. Abstract

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After gallium arsenide, diamond promises to become the new high-tech electronic substance. Materials scientists all over the world are working feverishly on the development of diamond coatings to make the decisive breakthrough and to obtain patents.

In 1792 Antoine Lavoisier showed that in the combustion of diamond, only carbon dioxide is liberated, that the noble stone thus consists only of carbon. Since then, charlatans and scientists alike have tried to reverse this process and convert carbon-containing substances into the gemstone. Recently, two methods were crowned by success:

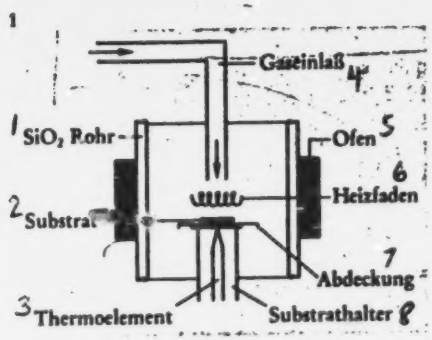
-In 1954 H. Tracy Hall et al. working at General Electric succeeded in obtaining diamonds from graphite at high pressure and temperature. The diamonds obtained are like the "natural" ones formed in the earth and are metastable at room temperature. But the diamond phase exists up to a temperature of 1100 degrees C.

-A technology that might become important in electronics was discovered in 1958 by W.G. Eversole at Union Carbide. Diamond layers were obtained by pyrolysis of methane. But since more graphite than diamond formed on the substrate, the process had to be interrupted frequently and the graphite etched off.

In 1977 significant progress was made by a Soviet group headed by B. Derjaguin and D.V. Fedoseyev at the Institute for Physical Chemistry in Moscow. The Soviet scientists studied the kinetics of the pyrolysis of hydrocarbons and pointed out the importance of atomic hydrogen. It is able to prevent the

precipitation of graphite. In 1981 B.V. Spitsyn, L.L. Bouilov and Derjaguin first produced epitaxial, monocrystalline diamond films on a diamond substrate. They used an electric discharge to release atomic hydrogen in the precipitation zone. The rate of growth of the diamond film was 1 µm per hour. Japanese research groups have been building on these successes. Pioneering work was done by Seiidiro Matsumoto et al. at the National Institute for Research on Inorganic Materials in Ibaraki. They used a tungsten heater (2000 degrees C) to dissociate hydrogen near the substrate (Figure 1). A methane-hydrogen mixture was fed continuously to the reaction chamber. In this case, diamond crystals were produced on the hot substrate. Microwave and radio frequency plasmas were also used for hydrogen dissociation. Today the precipitation of mono- or polycrystalline diamond layers with growth rates of 10 µm/h are possible. According to present knowledge, preventing the generation of carbon double bonds is decisive for these processes. They allow the undesirable growth of graphite. Due to the presence of H-atoms, the double bonds are broken and the single bond important for diamond growth is created.

Why does the diamond seem so attractive to scientists? First, the material is characterized by extreme inertness, great hardness, high thermal conductance, and--when undoped--by very good electrical insulating properties. Merely a good heat removal from the densely packed electronic components is an urgent task



Diamond Transistors Promise to be very fast and Insensitive to Thermal Effects

Key: 1-silicon dioxide tube 2-substrate 3-thermocouple 4-gas inlet 5-furnace 6-heating filament 7-cover 8-substrate holder

today for continued integration. Diamond has the high thermal conductance necessary for this; its value is even greater than for copper and silver. But diamond layers are attractive not only as substrates for electronic circuits. Through suitable doping it is possible to produce transistors with diamond as base material (instead of silicon). Diamond has a very large band gap of 5.45 eV compared to 1.1 eV for Si. The large band gap promises to make diamond transistors insensitive to temperature shocks and radiation effects. For instance, there is talk about using such transistors in the automobile or for telecommunications in space, where a high radiation level is encountered. Diamond transistors are to be produced in 1987 at the Japanese Sumitomo Co. Diamonds can probably be used to build very fast transistors. The speed of the free charge carrier in the diamond increases continuously with the electric field strength--unlike many semiconductors where the speed passes a maximum and then decreases with increasing field

strength. Since the puncture field strengths in diamond are very large, the expected charge carrier speeds are higher than in record-holder gallium arsenide.

Diamond also has fascinating optical properties. It is permeable to light above a wavelength of 230 nm. Its high heat conductance, together with the large band gap makes it possible to use this material for high energy laser mirrors. Diamond could even be used as a UV laser system.

But until these goals are reached, a lot of development work still has to be completed. Perhaps more likely is a diamond coating on kitchen knives or on the read/write heads of diskette systems.

OPTICAL CIRCULATORS AND INSULATORS

Magnetic Components for Optical Communications Engineering

Hans Jurgen Schmitt, Hans Dammann

When light passes through a transparent, magnetic crystal, the polarization of the light wave rotates as a function of the size and direction of the magnetization. The process is not reversible or, as is also said, it is non-reciprocal. This relation found by Faraday in 1845 (information box I) forms the basis for the use of optic isolators or circulators in modern optical data transmission. Such elements are needed to avoid a reaction from the optical system on the laser source. In many applications of laser light, this reaction is negligible, especially if the laser beam passes long distances without reflection. But if the laser light is fed directly to a "consumer", like a fiberoptic system, this can have a reaction on the source.

Such reactions lead to undesired fluctuations in frequency, phase and amplitude of the laser and consequently to an increase in the bit error rate (BER) in the system. Isolators in coherent optical systems with super-heterodyne reception where frequency changes must be below 1 MHz, are particularly important. The rquirements of insulators are accordingly high. For coherent systems with frequency coding, e.g. an insulation of 60 dB is

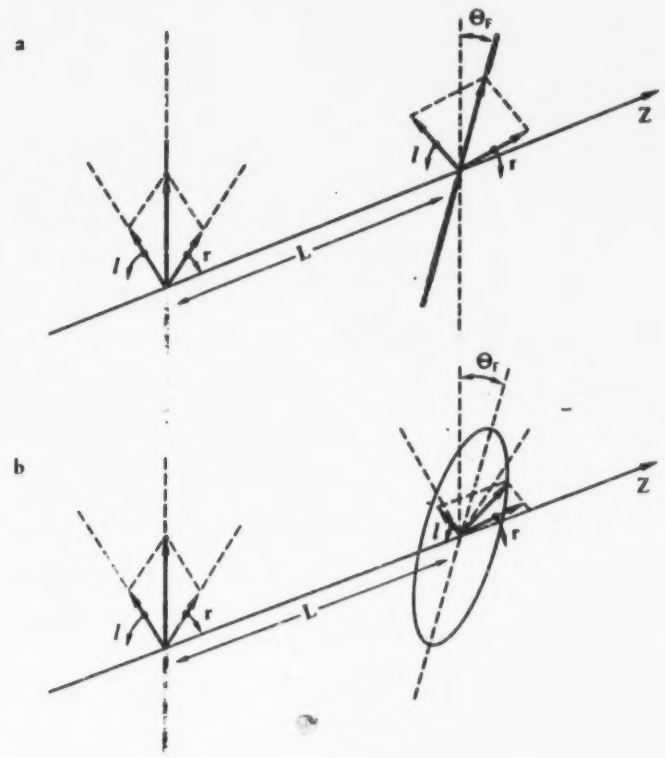


Fig. 1: Effect of a Faraday Rotator. Cleavage of a linear polarized wave into two opposing, circular polarized waves (l, r). a) Output superimposed on a linear polarized wave with a polarization rotated by Θ_1. b) with dichroism an elliptical polarization appears at the output.

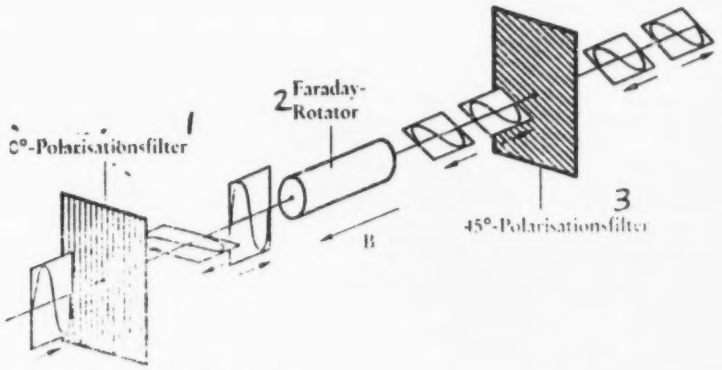


Fig. 2: [caption illegible]
Key: 1-polarization filter 2-Faraday rotator 3-polarization filter

required [1]. This means a power ratio of emitted to returned wave of 1,000,000 : 1 !

In addition to the aspect of noise reduction, other applications of circulators are in bidirectional fiber utilization to improve ring lasers for navigation systems and for signal separation in reflection measuring equipment. The development of integrable, non-reciprocal elements is currently under intense study.

Information Box I:

Faraday Effect

In magneto-optic crystals a linear polarized wave running in the z-direction is split into two circular polarized waves of different phase velocity (Figure I.1),

$$c_{r,l} = \frac{\omega}{\beta_{r,l}} = c_o \left(1 \pm \frac{\delta}{2}\right)$$

where ω is the cycle frequency, β the wave number (phase constant) and δ is the secondary diagonal of the dielectricity tensor:

$$\varepsilon = \varepsilon_o \varepsilon_r \begin{pmatrix} 1 & -j\delta & 0 \\ +j\delta & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

At the output the two waves are composed of a linear polarized wave with polarization rotated by /b/ . δ is on the order of 10^{-4}.

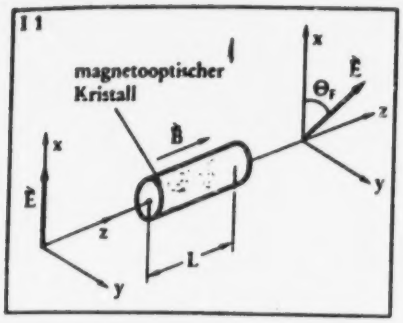


Fig. I.1: The Faraday Effect in a Magneto-optic Crystal leads to a Rotation of the Polarization Plane.

Key: 1-magneto-optic crystal

Information Box II:

Coupled Modes

Along the z-axis two initially decoupled waves, e.g. a TE-wave and a TM-wave are propagated with phase constants β_{TE} or β_{TM}. The difference in phase constants is $\Delta\beta = \beta_{TE} - \beta_{TM}$. Due to the secondary diagonal element o of the dielectricity tensor, a linkage now occurs so that energy periodically changes from the one wave type into the other wave type. If all the energy is the TE-type when z = 0, then for amplitudes of the TE-wave and the TM-wave we have:

$$A_{TE}(z) = \cos(\kappa z) + j\,(\Delta\beta/2\kappa)\sin(\kappa z)$$

$$A_{TM}(z) = -(K/\kappa)\sin(\kappa z)$$

with the coupling constants K and κ, where $\kappa^2 = K^2 + (\Delta\beta/2)^2$.

The value of K depends on the structure of the modes and is determined from the overlap integral:

$$K \approx \frac{\beta}{4} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \delta(x,y) e_x h_y \, dx dy,$$

where e and h are quantities of the electric field of the TE-wave or magnetic field of the TM-wave related to the unit power flux, and $\delta(x,y)$ is the secondary diagonal element which can be location-dependent.

The energies in the two modes are proportional to:

$$\left|A_{TE}(z)\right|^2 = 1 - \frac{K^2}{\kappa^2} \sin^2(\kappa z) \qquad \text{or}$$

$$\left|A_{TM}(z)\right|^2 = \frac{K^2}{\kappa^2} \sin^2(\kappa z).$$

These curves are illustrated in Fig. II.1 for $K^2 = \kappa^2$, i.e. $\Delta\beta = 0$, and $K^2 = 1/2\,\kappa^2$, i.e. $\Delta\beta = 2K$. For $\Delta\beta = 0$ there is complete modal conversion.

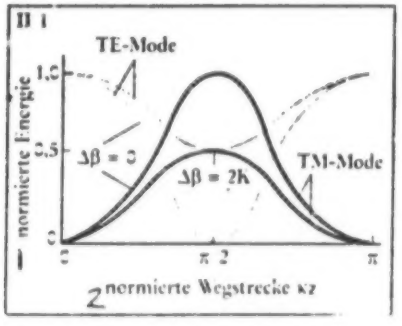


Figure II.1: Normed Energies in Coupled Modes as a Function of Coupling Length z for Different Accuracy of Phase Adaptation. For complete phase adaptation ($\Delta\beta = 0$), 100% mode conversion occurs. It is assumed that at the coupling point where z = 0, pure TE polarization is present.

Key: 1-normed energy 2-normed path distance

Physical Principle

In the simplest case of a homogeneous, magneto-optic solid, the mechanism of the Faraday rotator can be described as follows: Due to an external magnetic field oriented statically along the propagation direction, moving charges experience an additional Lorentz force due to electrons accelerated by the light wave. These forces are perpendicular to the direction of the polarizing electric field and perpendicular to the static magnetic field (information box I). The material is then anisotropic.

A linear polarized light wave can be split into two circular polarized components (Figure 1a). Both components have different phase velocities in the rotator. After passage through the rotator, the overlap of the circular components again leads to a linear polarized wave. However, its polarization plane is now rotated to the original direction.

To create a non-reciprocal component, like a circulator, the Faraday rotator is linked with a polarizer which only passes the wave rotated by the angle Θ_F (Figure 2). A returning wave polarized at this angle is rotated after passage through the Faraday rotator by $2\Theta_F$; for $2\Theta_F = 90^\circ$, it is then cancelled by a corresponding 0°-polarizer. If the extinction occurs by absorption as in microwave engineering, then we call this an isolator.

If the two circular components are absorbed differently, which is called dichroism, an elliptic polarization occurs at the

output of the rotator (Figure 1b). This limits the attainable isolation since the 0°-polarizer in Figure 2 can block elliptical polarized light only incompletely. This complex case of the Faraday rotator, where the coupling of light waves of different polarization (mode coupling) plays an important role, is described in information box II.

In practice the Faraday rotator is supplemented as follows:

-For applications in optical communications engineering, the effect should be independent of random polarization of the incident wave. In this case, the beam can be split into two orthogonal components, fed via two separate assemblies and then recombined.

-In order to avoid oblique polarization, an additional reciprocal polarization rotation by -45° is performed, so that on the way out cumulatively no polarization change will occur and on the return path a total of 90° is achieved.

Materials

The starting material for nearly all developments of non-reciprocal optical components is yttrium-iron granulate (YIG), which is a monocrystal for wavelengths $\lambda > 1$ µm having high transparency. The damping α is less than 3 dB/mm (Figure 3) there. The Faraday rotation Θ_F is wavelength-dependent. The 45°-length for $\lambda = 1.3$ µm is about 2.3 mm for a refractive index $n = 2.2$. This behavior is caused by a ferromagnetic resonance in the microwave range and a transition in the UV spectral range [2].

Premium optical granulate crystals are grown by the Czochralski method and are used for jewelry and for microwaves,

for YIG filters or delay lines. Numerous chemical substitutes allow variation of the optical properties. In particular, by partial substitution of yttrium by bismuth, the Faraday rotation can be reversed. Greater operating values can be obtained. The saturation magnetizing of pure YIG is at 0.17 Tesla, in the optic components external fields of a few 10^{-3} T are sufficient for complete magnetization.

For integrated optic systems, non-reciprocal elements with film or strip conductors of YIG or GdIG or YbIG with various substituents are suitable. Films with thicknesses up to a few 100 µm are generally deposited on a substrate crystal by liquid phase epitaxy.

As substrate with appropriate lattice constants, primarily Gd-Ga granulate (GGG) is suitable. Specific substitutions allow modification of optical properties of single layers. An overlap of several layers with different properties thus makes it possible to create film waveguides with more or less weak conduct of the optical wave. Due to the small values of magneto-optic coupling, even tiny anisotropy disturbs the refractive index. This necessitates an accurate control of crystal growth conditions.

The production of optic strip conductors a few µm wide uses etching processes on films with subsequent coating, but as a rule some slanting walls are created (Figure 4). More recent methods aim to produce YIG structures by sputtering [3]. The problem of linking the magnetic layers with the usual materials of semiconductor lasers, GaAs or InP, still has to be solved.

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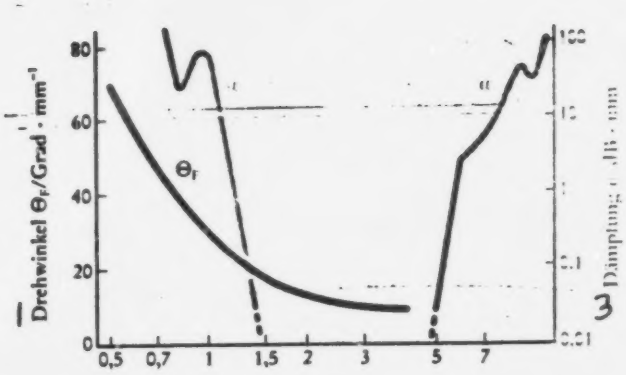
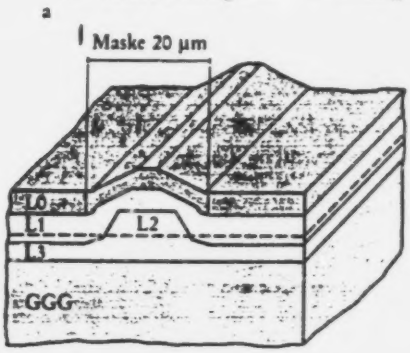
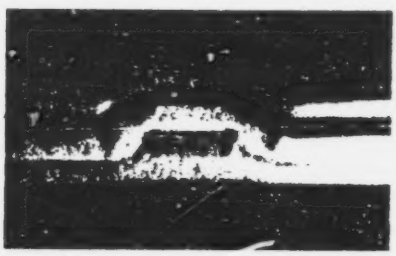


Fig. 3: Faraday Rotation and Damping in YIG (Yttrium-Iron Granulate) as a Function of Wavelength

Key: 1-rotation angle in degrees
2-wavelength 3-damping





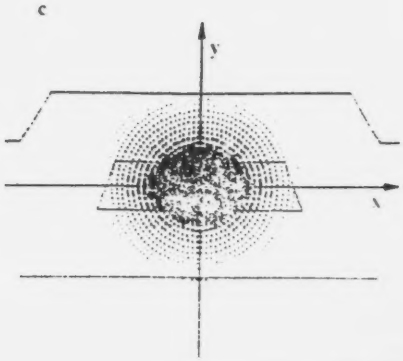


Fig. 4a) Magneto-optic Strip Conductor (buried channel waveguide) on Gd-Ga granulate (GGG) with core (L2) completely surrounded by a mantle layer (L1, L3); layer L0 is an absorption layer which suppresses mantle modes. b) Structure of the waveguide. c) Computed distribution of light intensity of the simplest wave.

Fundamentally different materials for isolators and circulators make up the magnetic semiconductors, like CdMnTe, which come into consideration primarily for wavelengths $\lambda < 1$ µm. The design length is ca. 1 mm for 45° rotation of red light. The damping here is 0.6 dB.

Finally, glass fibers can even be considered. The rotation relative to the transit route and the force flux density (Verdet constant) at $\lambda = 0.83$ µm is $v = 0.11^{\circ}/(mm\text{-}T)$ for SiO_2, so that sufficient polarization rotation is achieved with fibers of a few meters length.

Micro-optic Circulators

A polarization-independent micro-optic circulator for $\lambda = 1.3$ um is shown in Figure 5. As 45°-Faraday rotator we use a 2.3 mm long YIG cylinder with 6 mm diameter in the field of 0.25 T [4]. The reciprocal 45°-rotation occurs in a $\lambda/2$ quartz plate. Light coupling at the input E occurs through short glass fibers (pigtails) via small lenses. The polarization components transit two double-refractive prisms with small air gap. Suitable material for the prisms is Rutil composed of titanium dioxide. A polarization component is totally reflected at the boundary, while the other component continues under the Brewster angle and is not totally reflected until it reaches the following Rutil/air boundary. An identical combination of Rutil prisms is used to join polarization components at output A. The circulator has only

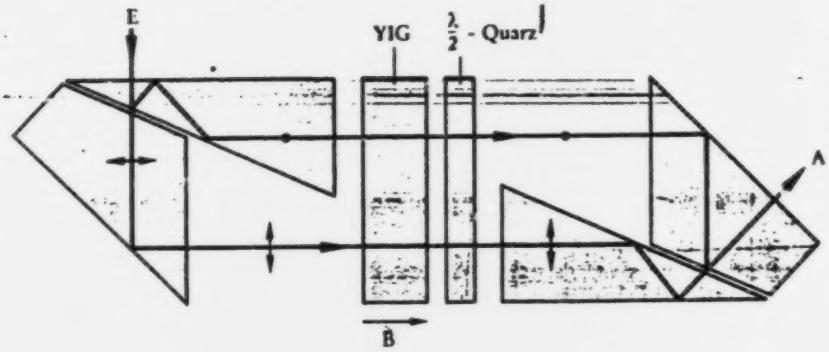


Fig. 5: Polarization-independent micro-optic circulator [4]. The polarization components are separated into two beams at input E due to total reflection or transmission at the Brewster angle in a prism device and are re-joined accordingly at output A. The non-reciprocal polarization rotation occurs in the 2.3 mm-thick YIG crystal, the subsequent reciprocal rotation occurs in a $\lambda/2$ quartz plate.
Key: 1-quartz

a matchbox size and delivers 32 dB isolation with regard to the returning beam and 2.3 dB transit damping at λ = 1.3 µm with a 3 dB wandwidth of just 0.5 µm.

The coupling or decoupling from a fiber and the Faraday rotation can also be combined in a magnetized YIG sphere which then works like a non-reciprocal lens [5]. Since single beams take somewhat different routes in the sphere, different Faraday rotations also occur. This is visible in a limitation of the isolation. With a sphere diameter of 2.1 mm, when coupling to mono-mode fibers, an isolation of 30 dB was measured at λ = 1.3 um. The coupling losses are 5.2 dB for mono-mode fibers, or 2 dB for multi-mode fibers.

Previoiusly attained micro-optic components already exhibit quite good isolation, but with relatively high damping of over 2

dB in the forward direction. The losses are attributed mostly to coupling losses between fiber and circulator.

Micro-optic components fit rather poorly into modern optical communications systems using waveguides. These components are hardly suitable for series production and integration with other system components (laser, fiber). Adjusting them within the system is complicated and expensive. So it is desirable to design the non-reciprocal optic components in a waveguide structure, so that integration with the other system components will be simplified. This has the added advantage that interim reflections are mostly eliminated and a defined mode propagation will allow more accurate dimensioning. However, other, primarily technological problems are encountered here which have not yet been fully resolved.

Integrable Structures

The lightwaves in integrated optic systems move in the form of discrete modes in thin strip lines a few μm wide. Integrable, non-reciprocal elements must be compatible with this strip structure, i.e. Faraday rotator, coupler and phase shifter are themselves constructed of strip lines. Three different types of non-reciprocal elements have been proposed.

Discrete Integrated Components

These are structured with separate Faraday rotator and reciprocal 45° converter in connection with integrated polarizers at the input and output. Creation of a suitable Faraday rotator

is particularly difficult here: In thin films or strip waveguides linear or circular polarized plane waves cannot propagate as in homogeneous material, rather the waves run in an optical zig-zag between the boundaries. The simplest possible wave types in films and strips are TE-waves (transversal electric waves) and TM waves (transversal magnetic waves). Such waves always appear when light falls obliquely on a boundary, and TE waves occur for perpendicular polarization and TM waves for parallel polarization with respect to the incident plane.

In the Faraday rotator of an optic isolator, a wave type, like an incident TE wave, must be converted about 50% into a TM wave due to the action of the magnetic field, so that at the output an overlap of 50% TE and 50% TM waves will occur. The polarization should thus lie exactly between perpendicular and parallel, corresponding to 45^{o} polarization rotation in micro-optic Faraday rotators. In another element a reciprocal 50% conversion must occur, so that on the outbound leg, cumulatively no conversion occurs and on the return leg, a complete conversion of TE into TM type occurs.

A sufficient mode conversion presumes that the corresponding TE or TM base modes have more of less the same propagation speed: Only then is the energy coupled optimally from one wave type into the other. This is called phase adaptation (information box II). This phase adaptation normally does not apply for optic waveguides, since the propagation conditions for the two polarizations are somewhat different (Figure 6). So a trick has

to be used and a phase adaptation brought about by additional means.

The range for manipulation of the phase velocity is not large. Thus it is expedient to begin from a structure with an inherently good phase adaptation.

This is the case when the actual waveguide differs very little from the surrounding medium. We call this a "weak guide" of the waves, whose fields extend rather far into the outside space. Such weak guiding structures can be created e.g. from films or strips with slightly differing doping. An arrangement with optic strip guides is shown in Figure 4. We see the layered structure on a gadolinium-gallium granular substrate crystal and the slightly slanting walls of the optic strip guide. The difference in refractive index between strips and cover layer is only $n_s - n_p \approx 0.004$. The thickness of the strip is then 6 to 7 µm, which corresponds to the diameter of a modern mono-mode glass fiber.

But this method is not sufficient for an efficient mode coupling. To optimize the mode conversion, the phase adaptation has to be improved. Mechanical stresses are one possibility for specifically affecting the refractive index. Mechanical stresses are present in the films and strips due to growth-related effects, but they cannot be accurately reproduced. But they can be additionally controlled by external pressure by using peizo-elements, and actually a precise phase adaptation can be achieved.

Thus we have simultaneously an "electronic knob" for subsequent tuning of phase adaptation [6].

Since the electromagnetic fields of the light wave in the strip guide extend far into the outside space of the surrounding medium for weak guides, a coordination of phase velocity can also be achieved by external cover layers with somewhat different effective refraction for TE or TM polarization. A relatively high refractive index makes the wave comparitively slower, a smaller index makes them faster. Naturally anisotropic crystals, like $LiNbO_3$ exhibit this property. But the parameters are expanded considerably by artificial anisotropic layers [7]. By using modern submicron lithography, periodic or statistical furrows can be produced which are filled with a different material (Figure 7). The trenches thus give the layer a preferred direction and thus a polarization-related refractive index which can be approximated. Depending on materials and structure parameters, a ratio of n-parallel/n-perpendicular up to 1.5 can be achieved, thus a significantly greater ratio than for natural crystals. It turns out that even small thicknesses of such "form-anisotropic" cover layers of < 1 µm are sufficient to cause phase synchronization, but the structuring must be quite accurate.

These changes seem to solve the problem of developing a suitable Faraday rotator. The second important subcomponent of the isolator, the mode-converter--which is to turn back the polarization after the Faraday rotator into the starting position--can be be designed in principle as single anisotropic

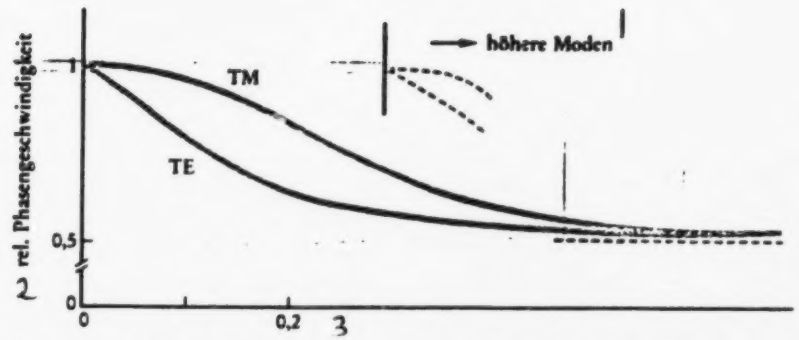


Figure 6: Relative phase velocities of the lowest transversal electric (TE) and transversal magnetic (TM) modes in a film waveguide with refractive index $n_F = 2$ as a function of relative layer thickness d/λ. Above $d/\lambda \approx 0.29$, additional modes appear with more complicated field distributions; such layer thicknesses should be avoided.

Key: 1-higher modes 2-rel. phase velocity 3-film thickness/wavelength

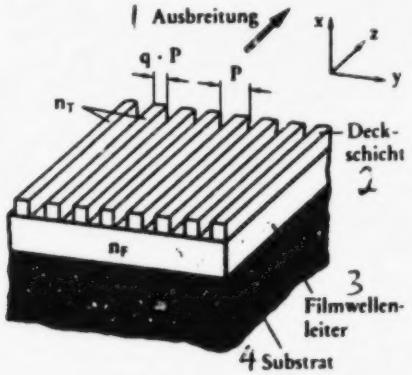


Figure 7: Film Waveguide with Artificial, Anisotropic Cover Layer of Dielectric Bars

Key: 1-propagation 2-cover layer 3-film waveguide 4-substrate

waveguides, e.g. of $LiNbO_3$, by liquid crystals or even by using artificial double-refractive cover layers. Also, in electro-optic materials, the reciprocal conversion can be controlled electronically via the electro-optic effect, so that any desired polarization rotation can be obtained "electrically" in the waveguide.

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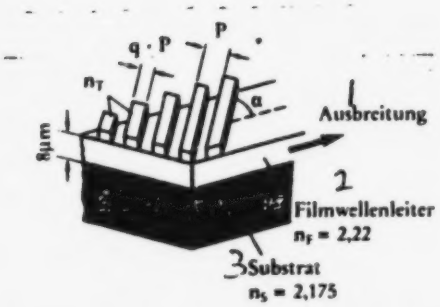


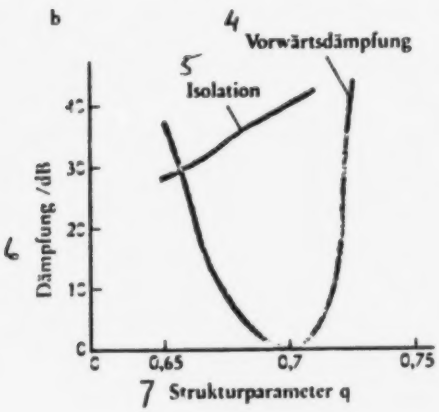
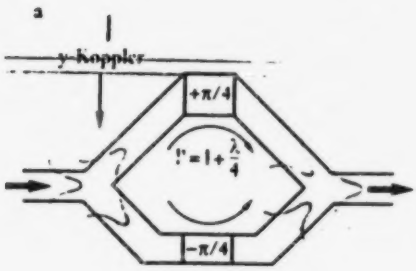


Fig. 8a) Semi-leaky isolator with artificial anisotropic cover layer [9]; λ = 1.3 µm. Length L = 2.5 mm, n_T = [illeg.]. b) Isolation and damping depend on the balance of non-reciprocal and reciprocal mode conversion which is determined by position of preferred direction (c) and dielectric anisotropy (structural parameter q, see Fig. 8a).

Key: 1-propagation 2-film waveguide 3-substrate 4-forward damping 5-isolation 6-damping 7-structural parameter



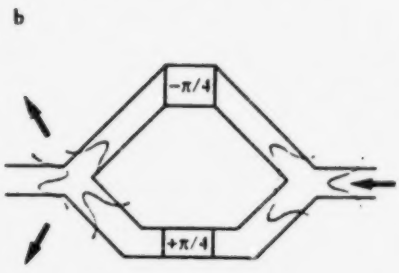


Fig. 9: Integrated optic isolator using the Mach-Zehnder Principle [10]. a) For light coupling, from the left the geometric path length difference is compensated ($l' - l = \lambda/4$) and the phase rotations in the two arms are also compensated; light is transmitted. b) For reverse light propagation, the two subwaves destructively interfere; light is not transmitted but absorbed or dissipated.

Key: 1-coupler

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The coupling conditions become more confused in optic strip conductors using integrated optics components for reasons of optimum coupling and decoupling of light. In these two-sided, laterally limited structures, more complicated wave types occur than in films, so-called hybrid waves resulting from a coupling of TE and TM waves at the complicated geometric edges. Current research is aimed as providing computer-based methods for graphic or numeric description of any multi-layered structures for direct calculation of propagation data.

Combined Integrated Structures

Under certain, precisely specified conditions, non-reciprocal, magneto-optic conversion and reciprocal conversion can be combined in one waveguide. This promises smaller design lengths, which is important mainly for reasons of light absorption. The design lengths of the waveguide structures are typically on the order of 5-10 mm for isolators. At a light wavelength of 1.3 to 1.5 μm, this corresponds to a length of ca. 1000 wave trains in the material. This is not quite easy to produce. The combination of the two conversions leads to other problems, especially of the difficult balancing of effects. On one hand, the phase adaptation must be maintained, on the other hand, an equal amount of reciprocal and non-reciprocal mode conversion must be created. Both are possible if an inner anisotropy of the waveguide or an external anisotropic cover layer can be used, and the preferred direction must be rotated compared

to the direction of wave propagation. The balance of effects can be achieved by inclining the magnetic field from the propagation direction.

The semi-leaky isolator [8] is less sensible; here the passing wave is guided with constant polarization, the returning wave is rotated in the polarization and thus leaks from the waveguide and is absorbed in the outside space. The emitted waves can exit at an angle so that quasi-automatic phase adaptation occurs with any emission mode. But an accurate local balance of reciprocal and non-reciprocal conversion is needed. The isolation rises proportional to the length of the element, which however must be greater than in ideal coordinated TE, TM-converter with phase adaptation. Bismuth-substituted granules with large Faraday effect and an artificial dielectric as cover layer for slightly conducting film waveguides yield design lengths of $L < 10$ mm for 40 dB isolation (Fig. 8). When specifying the reciprocal conversion percentage, which can be varied within a certain range e.g. by rotating the bar structure, only the non-reciprocal conversion need to adjusted. In this case no attention need be given to phase adaptation and exact design length. The adjustment can be done in certain limits by size or direction of the external magnetic field. So again we have an "electronic tuning knob" to optimize the desired function.

Mach-Zehnder Structures

The lightwave is divided per Fig. 9 onto two mono-mode waveguides. The optic length of the waveguides differs by exactly $\lambda/4$ or 90^{o}. In both waveguides there are additional, non-reciprocal phase shifters. These waves are joined in simple Y-couplers at the output.

These couplers perform a very important task in the isolation: For a left-incident wave, different path lengths and phase shifts are compensated. The waves overlap at the output to form a mode structure which is coupled by the coupler into the outbound line. For the returning wave, the wave fields are subtracted at the output. The uneven field distribution generated by the overlap then does not fit into the mono-mode guide; the energy is reflected or dissipated.

Such structures are currently under investigation in Japan, but no experimental results have yet been published.

Outlook

In optic transmission systems with glass fibers, the system dynamics is limited typically to about 30 to 40 dB due to the available laser power and detector sensitivity. All measures to improve the S/N-ratio are of great practical importance.

According to the present status of research and development, isolators and circulators based on the Faraday effect in micro-optic design with glass fiber junctions can already be used for coupling, even though the additional damping of 2-3 dB at ca.

30 dB isolation is still relatively high. Improvements in frequency stability and noise reduction are experimentally confirmed.

For the particularly important, integrated optic components, different solutions with or without phase adaptation of modes have been proposed. For films and strip guides, the problem of phase adaptation of quasi-TE and quasi-TM modes can be solved, but not all parameters can be technologically reproduced, so that the delicate balance of phase velocities--which may differ only by fractions of a thousandth--cannot be secured over distances of a few 100 up to perhaps 1000 wavelengths.

In the semi-leaky structure the difficult balance is between reciprocal and non-reciprocal conversion. In the Mach-Zehnder arrangement, probably the large size is a factor. Thus for all designs, a type of additional electronic or even mechanical "after-adjustment" will be needed. Possibilities for this are mechanical pressure, rotation of the anisotropy axes, external magnetic field, perhaps also temperature.

In addition, the integration of magnetic materials into the usual substrate of integrated optics has to be explained. Further investigation of the sputter-tempering method appears promising for applying non-reciprocal, magnetic materials on semiconductor layers.

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